TRANSVERSE DEFLECTING RF STRUCTURES IN THE DESIGNED QBA LATTICE OF TAIWAN PHOTON SOURCE*

H. Ghasem#, School of Particles and Accelerators, IPM, P.O.Box 11395-5531, Tehran, Iran
G. H. Luo, NSRRC, Hsinchu 30076, Taiwan

Abstract

A pair of transverse deflecting RF cavities in the quadruple-bend achromat (QBA) low emittance lattices of 3 GeV Taiwan Photon Source (TPS) has been studied for generating ultra short X-ray pulses. The QBA lattice allows us to have alternatives for the locations of the deflectors. We proposed three possible configurations for locations of the deflecting structures in a super-period of the TPS. It is found that use of such deflecting cavities in the middle of two QBA lattices in a super-period seems to be more favourable for generating ultra short X-ray pulses using this method.

INTRODUCTION

The typical rms bunch length in a storage ring is usually about several tens of picoseconds (ps). This range of pulse duration is useful in numerous experiments but shorter pulses of subpicoseconds radiation, such as those associated with ultra fast phenomena, would extend the scientific frontier. Many efforts have been made to produce shorter X-ray pulses in synchrotron radiation facilities. As a third generation light source, Taiwan Photon Source (TPS) will produce about 19 ps-long (rms) X-ray pulses by operating the accelerating RF cavity at 1.1 MV. The TPS is made of six super-periods, each consisting of two quadruple-bend achromat (QBA) cells [1]. The QBA cell consists of two double-bending achromat (DBA) cells of unequal bending lengths associated with the outer and inner dipoles. This type of lattice has some advantages over the double-bend achromat or the double-bend nonachromat by providing a small natural beam emittance and some zero dispersive straight sections. Exploiting these advantages helped us employ the transverse RF deflectors [2-5] to produce subpicosecond photon pulses. In this concept, the transverse deflecting RF cavity was employed to produce a correlation between vertical momentum and longitudinal position of electrons in a bunch. For this purpose, a deflector must be worked in a TM_{110} mode. The sinusoidal vertical kick from the deflector leads to a head-tail oscillation of the stored electron bunch in the opposite direction, vertically. In order to confine this coupling in a section of storage ring, a second deflecting structure must be placed at an integer number of half betatron wavelengths downstream from the first structure. It provides the perfect compensation for all distortions to the longitudinal and transverse motion of the electrons made in the first cavity. If an insertion device (ID) like an undulator or a wiggler, as a radiator, is placed in between the deflecting cavities, the radiated photons would have some correlations among their time, vertical position, and vertical slope. In order to reduce the beam size in the radiator source and maximize the chirp of the slope, it is advantageous to place the ID at locations that are approximately $m\pi$ (m is an integer number) distant from the first cavity in vertical phase advance. To acquire a shortened X-ray pulse, the radiated X-ray is cut by a slit, and to enhance this effect an asymmetric crystal [6] can be used.

The TPS ring contains six long straight (LS) and 18 short straight (SS) sections each 10.91 and 5.31 m, respectively. Around one third of the ring is composed of straight lines accommodating special devices such as deflecting structures. Ten families of quadrupoles and eight families of sextupoles with mirror symmetry are employed in a super-period. Fortunately, the vertical phase advance in each QBA lattice is about 2π which is in favour of the deflecting structures. And three alternative locations for placing the deflectors are designated in a super-period at TPS. To elucidate the effects of deflectors in each alternative location, five watch points were established in the system. They were marked (W1) before the first cavity, (W2) after the first cavity, (Wu) at the center of the undulator as the radiator, (W3) before the second cavity, and (W4) after the second cavity, as displayed schematically in Fig. 1. All watch points were set on the coordinate mode. In addition, a bunch of 10000 electrons with a Guassian distribution was tracked through each alternative configuration. In order to produce rapid chirp regarding the quantum life time limitation, the cavities are set to be in 8^{th} harmonic of the main RF frequency for all configurations. The description of the three alternative configurations is as follows.

CONFIGURATIONS OF DEFLECTING STRUCTURES IN TPS

In the first configuration, the deflecting structures were situated in free dispersion regions at the beginning and at the end of a QBA cell, as shown in Fig. 1(a). The systematic fine adjustment of the deflectors positions yielded a difference in the horizontal and vertical phase advances of almost 13.71 and 6.2836 ($\approx 2\pi$), respectively. The distance from the deflector center to the narrowest aperture with no elements in between is D = 5.3 m. For the vertical chamber size of 2A = 9 mm, the maximum deflecting voltage ($V \le \frac{EA}{D}$) is 2.5 MV. The nominal

*The work is supported by NSRRC.
Email address: ghasem@nsrrc.org.tw

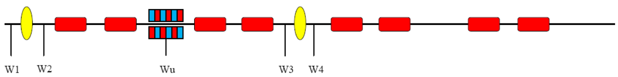

Figure 1(a): The deflecting cavities in the beginning and at the end of a QBA cell (first configuration).

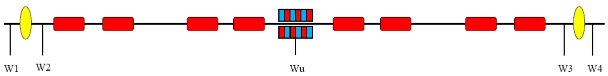

Figure 1(b): The deflecting cavities in the beginning and at the end of a super-period (second configuration).

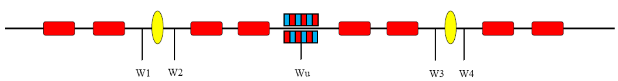

Figure 1(c): The deflecting cavities in the middle of the two QBA cells in a super-period (third configuration).

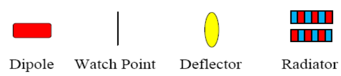

Figure 1(d): Key to symbols

vertical position of the electrons was about several microns when the deflectors were off, but it was increased by almost a thousand times after a single turn for 2.5 MV vertical kick. This indicates imperfect cancellation of the first kick in this configuration. One can generally expect that the cancellation process would be improved by adjusting the lower vertical kick voltages, but operating deflectors even in low voltages revealed that the kick cancellation process is not as efficient as the other two configurations and it greatly degraded the transverse emittance of the electron beam. This is related to the QBA lattice functions being different at the position of the two deflectors. To decrease these harmful effects, we reduced the first kick down to 0.5 MV and kept the second kick fixed on 2.5 MV and tracked the electron bunch for many turns. As a result, the vertical emittance blow up became large as compared to the other two configurations (see Fig. 2) and the minimum duration of pulses could not be obtained. Thus, we eliminated the first configuration from our option list.

In the second configuration, the deflectors were located in the beginning and at the end of a super-period, as shown in Fig. 1(b). The difference in horizontal and vertical phase advances of the deflectors were adjusted to be around 27.32 and 12.57 ($\approx 4\pi$), respectively. The vertical beta function at the deflecting cavities and the radiator are 8.93 m and 1.37 m, respectively. Moreover, the dispersion function at the cavities and at the center of the radiator is zero. Although the deflectors have the same lattice functions, the numerous nonlinear elements in the large distance separating them, 78.67 m, greatly affect the tilted bunch and generate error in the vertical slope of the electrons which in turn degrade the transverse emittance. Furthermore, two out of six long straight sections of TPS would be occupied. In this configuration, the distance from the deflector center to the narrowest aperture with no elements in between was 4.28 m and the deflecting voltage could not exceed 3 MV. Hence, for producing minimum duration of X-ray pulses, the deflecting voltages were set at 3 MV. Finally, the electron tracking revealed that the cancellation of the first kick was rather acceptable.

In the third configuration, the deflectors were located in the middle of the two QBA cells in a super-period where two dispersive short straight sections were devoted to the deflectors and the ID was placed at a free dispersive straight section between the deflectors as shown in Fig. 1(c). Since, the direction of the deflecting kick in TPS ring is vertical and primarily irrelevant to the horizontal dispersion, the effect of dispersion function can be ignored at the deflectors. The positions of the deflectors were adjusted to yield a difference in horizontal and vertical phase advances of 13.46 and 6.28 ($\approx 2\pi$), respectively. The distance between the deflectors is 36.20 m. Since the distance from the first deflector to narrowest aperture was 2.10 m, then the maximum kick voltage became around 6 MV. The vertical beta function at the deflectors and the ID were 1.45 and 1.37 m, respectively. To observe the kick cancellation process, the deflectors were operated at 6 MV and the electrons were tracked. It was seen that the kick cancellation seems as sufficient as the second configuration.

In the 2nd and 3rd configurations, the deflectors were seemed to produce almost equal electron vertical correlations at the ID location. Moreover, although the first kick was almost reversed by the second deflector, the emittance seems to grow from its nominal value of around 3 nm-rad.

Since the balance of the two synchrotron radiation effects (the particle oscillation damping and excitation) determines the equilibrium transverse emittance of the electrons in the storage ring, the electrons were tracked through the system for many turns. The transverse damping time is almost 13 ms in TPS so the equilibrium transverse emittance can be observed after 8000 turns. Thus, one thousand electrons were tracked for 8500 turns and the simulation results for h=8 for all three configurations are presented in Fig. 2.

To further compare the 2nd and 3rd configurations, electron tracking for many turns at various deflecting voltages was performed. As a result, the equilibrium vertical emittance for both On/Off modes of the interior sextupoles is shown in Fig. 3. Although the equilibrium horizontal emittance did not change significantly when the interior sextupoles were switched off, the eventual vertical emittance degradation was considerably large. For the highest deflecting voltages of 3 and 6 MV in the configurations, the eventual vertical emittance in the 2nd and 3rd configurations blow up 12.3 and 4.6 times of the nominal value when the interior sextupoles were switched on as presented in Fig. 3(b). Meanwhile, operating the deflecting voltages at 2 and 5 MV, the equilibrium vertical emittance degradation for both configurations became comparable. Since increasing the deflecting parameters enlarges the equilibrium vertical emittance and lessens the emitted photon duration, we chose the 3rd configuration and operated the deflecting structures at 6

MV and the 8th harmonic of the main RF frequency. We further kept the interior sextupoles switched on to minimize the equilibrium vertical emittance of the stored electrons and as a result, the equilibrium horizontal emittance increased moderately to 3.4 nm-rad.

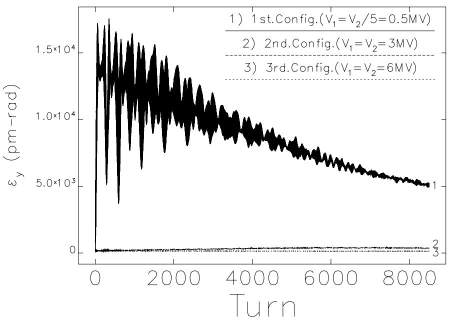

Figure 2: The equilibrium vertical emittance for all three configurations. The deflecting voltages of the first and second cavities are equal for both 2nd and 3rd configurations but for the 1st configuration, the first cavity voltage is one fifth of the second. The interior sextupoles were switched on in between the cavities.

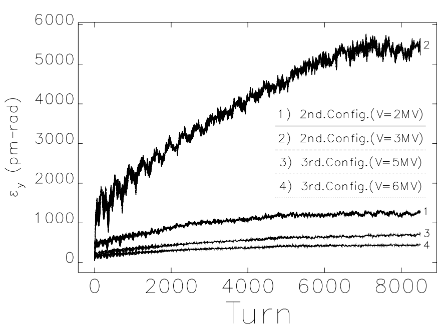

Figure 3(a): The equilibrium vertical emittances for the 2nd and 3rd configurations for various deflecting voltages. The interior sextupoles were switched off.

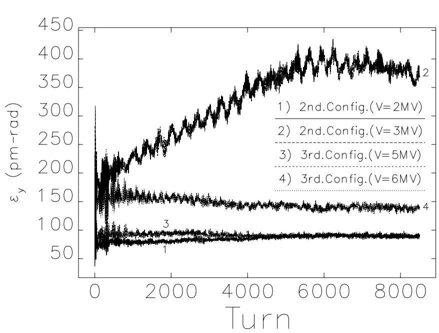

Figure 3(b): The equilibrium vertical emittances for the 2nd and 3rd configurations for various deflecting voltages. The interior sextupoles were switched on.

For comparative purposes, the selected configuration was run at different voltages and harmonics and results are presented in Fig. 4. It can be observed that the degradation of horizontal emittance from the nominal value is not significant, especially for lower voltages.

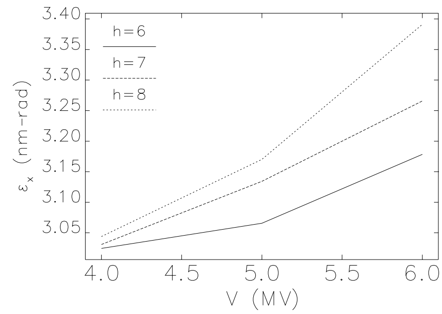

Figure 4(a): The eventual horizontal emittances in the 3rd configuration versus the deflecting voltages for various harmonics. The interior sextupoles were switched on.

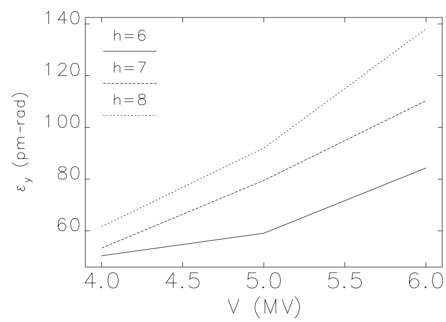

Figure 4(b): The eventual vertical emittances in the 3rd configuration versus the deflecting voltages for various harmonics. The interior sextupoles were switched on.

CONCLUSION

We have studied the transverse deflecting RF cavities in the QBA lattices at TPS to generate ultra short X-ray pulses. Three configurations for locations of the deflectors were investigated. The results showed that the first configuration due to the imperfect vertical kick cancellation of electrons by the second deflector had been excluded and the third configuration was preferred over the second due to the lower eventual equilibrium emittance. It was observed that the equilibrium vertical emittance in the 2nd configuration for the 8th harmonic at 3 MV was 2.6 times of the 3rd configuration for the same harmonic at 6 MV.

REFERENCES

[1] S. Y. Lee et al.: Review of Science Instrument 78 (2007) 05510.
[2] M. Borland: Phys. Rev. ST Accel. Beams 8 (2005) 074001.
[3] A. Zholents et al.: NIM-A 425 (1999) 385.
[4] M.Katoh: Jpn. J. Appl. Phys. 38 (1999) 547.
[5] H. Ghasem and G. H. Luo: Proceedings of EPAC, Genoa, Italy, (2008) 2025.
[6] N. Watanable et al.: J. Synchrotron Rad. 6 (1999) 64.